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EFFECTS OF ENERGY PER-UNIT LENGTH ON THE STRUCTURE AND HARDNESS--ETC(U)
MAR 78 G L PETROV, M D SHCHIPKOV

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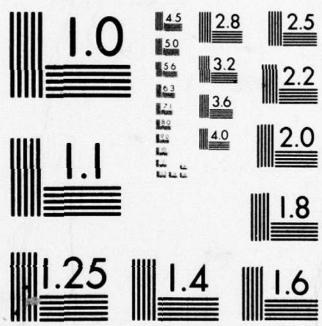

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TITLE: Effects of Energy Per-Unit Length on the Structure and Hardness of the Metal in the Weld-Affected Zone in Welding α-Ti Alloy

(Vliyaniye pogonnoy energii na strukturu i tverdost' metalla okoloshovnoy zony pri sbarke α-splava titana),

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EFFECTS OF ENERGY PER UNIT LENGTH ON THE STRUCTURE AND HARDNESS OF THE METAL IN THE WELD-AFFECTED ZONE IN WELDING ALPHA Ti ALLOY.

Ti ALPHA TO Ti BETA

Effects of Energy Per-Unit Length on the Structure and Hardness of the Metal in the Weld-Affected Zone in Welding α-Ti Alloy

[Petrov, G. L., Shchipkov, M. D; Trudy Leningradskogo Poli tekhnicheskogo Instituta im. M.I. Kalinina; No. 245, 1965, pp. 59-65; Mashinostroyeniye Publ. House, Moscow; Russian]

Weldments of technical-grade titanium and some of its alloys can have lower mechanical properties in the weld-affected zone as a result of structural transformations. According to data provided by a number of authors ~~[1, 2, 3, 4]~~, sections of the weld-affected zone heated in the process of welding to temperatures above polymorphous transformations $Ti_{\alpha} \rightarrow Ti_{\beta}$ develop grain growth and the metal in this zone after cooling off ~~may~~ show lower plasticity. The strength properties of the metal in this zone either increase somewhat (at high cooling rates) or decrease (at low cooling rates) ~~[2]~~.

The amount of increase in the grain size of the B-phase depends on the temperature at which the metal was heated above the polymorphous transformation point, the aging time at this temperature and the chemical composition of the Ti alloy. In the most general case, grain sizes are determined [5] by the following equation:

$$D = kt^n, \tag{1}$$

where D is the mean grain size;
k is a constant, depending on the metal's temperature & composition;
t is holding time;
n is an indicator depending primarily on the alloy's composition.

According to Eg. (1), grain size is affected by the metal's composition and holding temperature and aging time. For the metal of the weld-affected zone, grain growth of the β-phase takes place within the temperature intervals from the polymorphous transformation point to the melting temperature. The duration of the effect of these temperatures depends on energy per-unit length and may vary within wide limits in welding Ti of various thicknesses.

Ref [1] cites the results of a study on the effect of energy per-unit length in welding technical grade Ti of 2 and 4.5 mm thick.

The energy per-unit length was 1070; 1430 and 1990 cal/cm. On the basis of analyses, the investigators established that an increase in energy per-unit length from 1070 to 1990 cal/cm causes a fairly

high grain growth (about twelvefold), some drop in strength and a marked reduction in the plastic properties of the metal in the superheated zone.

The objective of this study was to establish the relationship of the hardness and the pattern of structural transformations in the metal of the weld-affected zone during either argon or flux-shielded welding of 20-30mm thick alloy 3. The effect of energy per-unit length on both the structure and hardness of the metal in the weld-affected zone during single-and four-bead deposition by argon arc welding using tungsten and comsumable electrodes, and single and four-head deposition by automatic AN-T3 flux-shielded welding. The welding specifications of all experimental specimens are shown in Table 1.

Welding Specifications
for Experimental Specimens   Table 1.

(1) Маркировка опытного образца	(2) Присадка, электродная проволока	(3) Число проходов, слоев	(4) Режим сварки: (5) сварочный ток, а	(6) напряжение на дуге, в	(7) скорость сварки, м/ч	(8) погонная энергия, кал/см	(9) Система защиты
1	(10) Вольфрамовый электрод без присадки	1	100	12	22	260	(14) Аргон марки А
2	(11) То же	1	170	12	22	440	(11) То же
3	„ „	1	230	16	22	800	„ „
4	(12) Вольфрамовый электрод, присадка ВТ-1	1	230	17	22	850	„ „
5	(11) То же	1	310	18	22	1200	„ „
6	(10) Вольфрамовый электрод без присадки	1	450	34	22	3370	„ „
7	(12) Вольфрамовый электрод, присадка ВТ-1	4	230	17	22	850	„ „
8	(11) То же	4	310	18	22	1200	„ „
9	(13) Электродная проволока ВТ-1	1	420	42	50	2400	(15) Флюс АН-Т3
10	(11) То же	4	420	42	50	2400	(11) То же
11	„ „	4	420	42	36	3390	„ „
12	„ „	4	420	42	22	5500	„ „
13	(10) Вольфрамовый электрод без присадки	4	360 250 200 100	20 16 17 15	22	1500 880 740 320	(14) Аргон марки А

Legend:

1. specimen marking
2. filler, electrode wire
3. number of passes, layers
4. welding mode
5. welding current, amp
6. arc voltage,
7. welding speed, m/hr
8. linear energy kcal/cm
9. protection system
10. tungsten electrode without filler
11. same
12. tungsten electrode, VT-1 filler
13. VT-1 electrode wire
14. A-grade argon
15. AN-T3 flux

To determine the microhardners, microsections of all the plates were treated with hydrofluoric acid. The microsections were then used for studying the structure of the weld metal (both with bead disposition and those without the use of filler layer), the metal of the heat-affected zone, and the base metal. Those with bead disposition using various energy per-unit length values, were used for determining the width of the heat-affected zone; the microsection pattern was magnified using an epidiascope. Changes in the hardness of the weld-affected zone metal as a function of energy per-unit length of the experimental beads were determined from microhardness measurements made using a PMT-3 device for a 100g load and Vickers hardness measurements by a TP device using a 10 kg load.

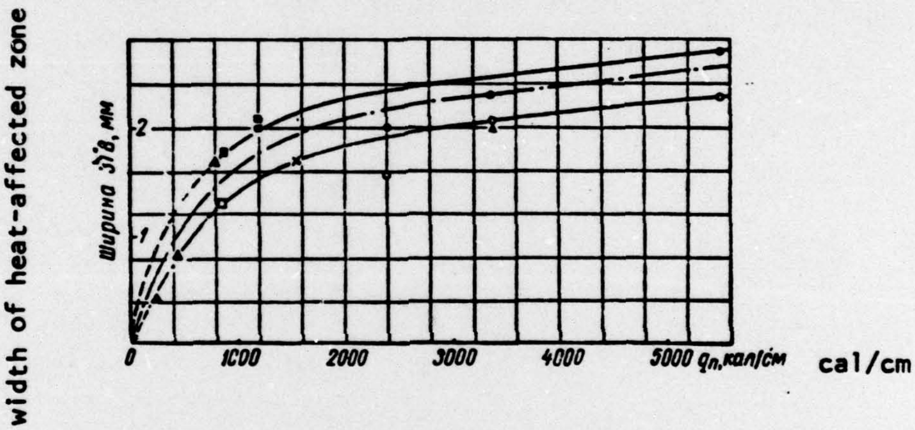


Fig. 1. Width of heat-affected zone as a function of energy per-unit length.

Argon arc welding by tungsten electrode:
▲ - single-bead deposit, + four-bead;
Argon arc deposit with filler; □ - single-bead;
■ - four-bead; automatic flux-shielded deposit;
○ - four-bead; ● - three-bead.

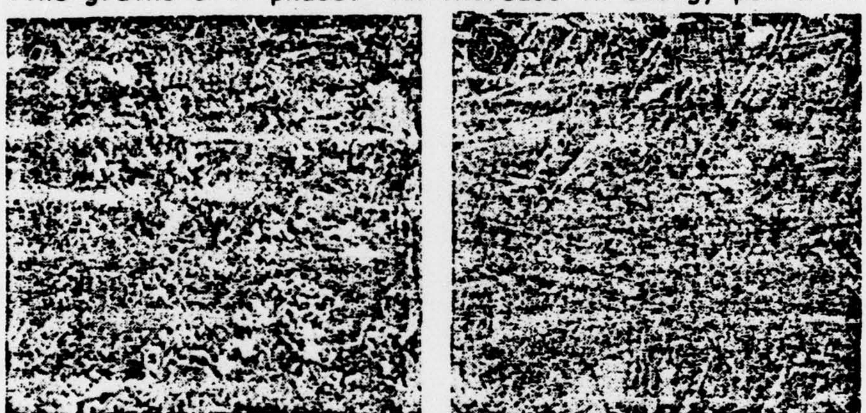
Changes in energy per unit length within the test limits from 260 to 5500 cal/cm widens the overall width of the heat-affected zone from 0.6 - 0.8 to 2.5 - 3 mm (Fig. 1). The widening of the heat-affected zone is most noticeable after an increase in energy per-unit length from its minimal values to 800-1000 cal/cm. With a further increase in energy per-unit length the widening of the heat-affected zone is much slower.

The magnitude of energy per-unit length in welding affects both the structure of the weld metal and that of weld-affected zone.

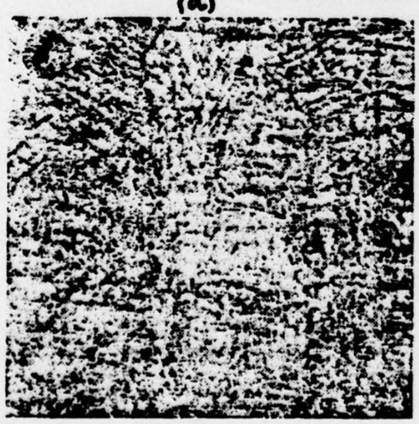
A study on the metal in the weld made with a minimum of energy per-unit length of 260 cal/cm revealed rather fine grains of the primary B-phase along the boundaries of which there were grains of the α-phase (Fig. 2,a).

inside the grains there was fine needle-shaped martensite of the α'-phase. As the energy per-unit length is increased to 2400 cal/cm for AN-T3 flux-shielded welding the primary grain size of the B-phase markedly increases. The weld metal grains are elongated (Fig. 2,b); along the primary grain boundaries there is the α-phase; the α'-phase is of coarse, martensitic structure (Fig. 2,c).

To determine the effect of energy per-unit length on the grain size of the metal in the weld-affected zone the authors made a metallographic study of the microstructure using small magnification (x50). Fig. 3 is a photograph of sections of the heat-affected zone near the specimen's fusion boundary (Table 1). For minimum linear energy (specimen 1), the fusion boundary shows sections of α'-phase and fine grains of α-phase. An increase in energy per-unit length



(a) (b)



(c)

Fig. 2. Microstructure of weld metal and the weld-affected zone x 100:
a - specimen #1, transition zone;
b - specimen #9; weld metal;
c - specimen #9, heat-affected zone

Fig. 3. Microstructure of the heat-affected zone near the fusion boundary x 50.

markedly increases the grain size. At maximum energy per-unit length (Specimen 12), nearly the entire visual field is taken up by one primary grain of the β-phase, along the texture of which there are fairly fine grains of α-phase and α′-phase, both having a coarse martensitic structure.

Fig. 4, a is a diagram of measuring the microhardness of the weld metal and the weld-affected zone metal. The microhardness was determined on microsection that were machine-polished and then chemically etched in concentrated hydrofluoric acid. For control measurements, some of the microsections were electropolished. The measurements were made at points spaced 0.05-0.2 mm apart, depending on the cross section of the deposit and the width of the heat-affected zone.

Fig. 4,b shows microhardness measurements on all experimental specimens as functions of energy per unit-length and cooling rates of the metal in the weld-affected zone. The cooling rates were calculated according to N. N. Rykalin's method [6] using the mathematical formula of a heat point source on a semi-infinite body. Since the microhardness measurements within one weld section or weld-affected zone showed a wide variance of microhardness values, the authors measured the Vickers hardness on these microsections using a 10-kg load. At this point the indentations for hardness measurements were set up not along a straight line crossing the seam and the heat-affected

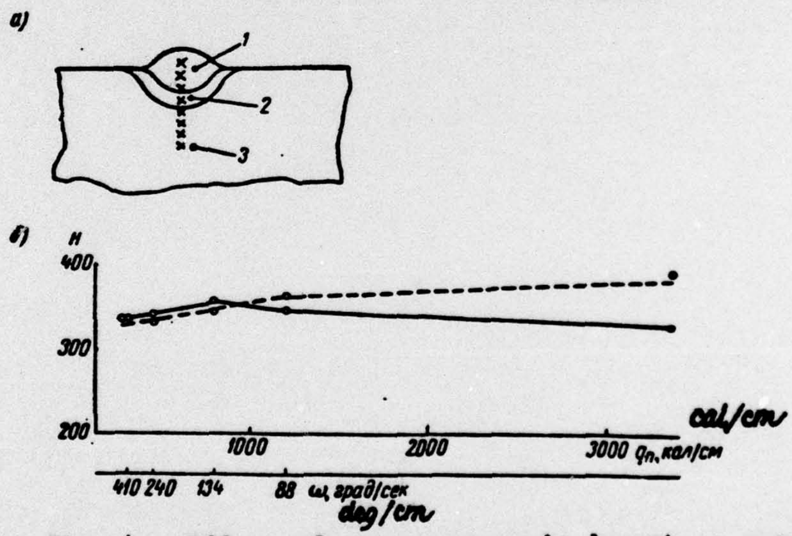


Fig. 4. Effect of energy per-unit length on metal microhardener of welds: a - microhardness measurement diagram. 1 - weld metal; 2 - heat-affected zone; 3 - base metal; b - changes in the microhardness of the weld metal and the heat-affected zone as a function of energy per-unit length: ——— heat-affected zone; ----weld metal

zone in the area of the weld root but merely along the heat-affected zone at some distance from the futron boundary.

The Vickers hardness results are given below.

Маркировка образца в соответствии с табл. 1 1	1	2	3	4	5	6	7	8	10	11	12
Твердость по Виккерсу 2	284	286	280	262	262	272	259	254	273	273	252

1 - specimen markings according to Table 1
2 - Vickers hardness

In order to establish feasible time-related changes in the hardness of the weld metal on the heat affected zone, the microhardness measurements were made not only immediately after the material was welded (after several days as the microsections were being prepared) but also after five or nine months of aging (storing) at room temperatures. Repeated post-aging measurements have shown that the hardness values in the base metal as well as that of the heat-affected zone and the weld remained at the initial level with the usual variance of about HV350.

The hardness measurements obtained in this study attest to the absence of any noticeable changes in the properties of the metal both in the zone and in the weld even with considerable changes in the energy per-unit length in the process of welding. However, with an increase in energy per-unit length, the hardness of the metal in the weld-affected zone somewhat decreases. This indicates that the alloy is slightly sensitive to the welding heat when changing the energy per-unit length from 260 to 5500 cal/cm.

Under fairly satisfactory shielding, for example, under argon-arc welding conditions, the hardness readings of the metal in the weld, the heat-affected zone and in the base metal are almost the same.

Conclusion.

1. The width of the heat-affected zone increases with an increase in energy per-unit length. Changes in the size of the heat affected zone with changes in energy per-unit length are hardly related to the method of electric arc welding. The heat-affected zone widths for a given energy per-unit length in both argon arc welding and automatic flux shielded welding are comparable.

2. The hardness of the weld metal slightly increases while that of the heat-affected zone slightly decreases with an increase in energy per-unit length within 260 and 5500 cal/cm.

3. Energy per-unit length affects both the structure of the weld metal and that of the weld-affected zone. At low energies and relatively high cooling rates the weld metal shows a fairly fine grain of the primary β-phase with α-phase separating along the boundaries. Inside the grains there is the fine needle-shaped martensite of the α'-phase. As energy per-unit length is increased, the primary grain size of the β-phase markedly increases, while the α-phase assumes the appearance of a fine grid along the boundaries of the elongated primary grains.

4. At low energy per-unit length values, the heat-affected zone shows a finely grained polyhedral structure with a fairly large amount of α'-phase section having the strucutre of fine-needled martensite.

An increase in energy per-unit length causes an increase in grain size and some fragmentation of the α-phase grains. The amount of α'-phase decreases causing a reduction in the hardness of the heat-affected zone metal.

5. The microhardness measurements of both the weld metal and the heat-affected zone in experimental specimens after welding and in those that were aged for about nine months yielded about the same results, this attesting to the absence of changes in hardness in time both in the heat-affected zone and in the weld.

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